

Etkins and Epstein (1) have suggested that the net discharge of polar ice sheets in the past century, inferred from global sea level rise, may (i) substantially account for observed long-period variations of the earth's rate of rotation by changing the planetary moment of inertia and (ii) substantially affect global mean temperature by means of the latent heat absorbed by melting ice. These suggestions, if verified, have major implications: (i) observed changes in the length of the day could provide a useful measure of polar ice sheet mass balance and (ii) climate model studies of the global temperature trend would require substantial revision.

Etkins and Epstein used the sea level analysis of Emery (2), who found a rise of 30 cm per 100 years for the period 1935 through 1975. This result is weighted heavily by the large number of stations on the east coast of the United States, which is a region of known isostatic subsidence. Gornitz *et al.* (3) analyzed all tide gauge data available from the Permanent Service for Mean Sea Level, Birkenhead, England, weighting each of 14 geographical regions equally. With all stations of record length 20 years or more included, except several stations in regions of known local subsidence, Gornitz *et al.* obtained a global mean sea level rise of 12 cm in the past 100 years and 10 cm after correction for long-term shoreline movements. To minimize the possibility of bias due to station selection, we repeated the analysis of Gornitz *et al.* (3) but included all stations; the result was a 13-cm uncorrected sea level rise in the past 100 years and 10 cm after correction (Fig. 1, curve a). We estimate the uncertainty as ~ 5 cm, due primarily to the difficulty of separating eustatic sea level rise from shoreline movement. Our procedure of averaging trends of all independent regions appropriately weights the data; more formal analysis of the global distribution of sea level change does not provide a more meaningful global trend.

Although a substantial part of the observed sea level rise may be attributable to thermal expansion (3), we can obtain an upper limit for the effect of ice sheet melting on the earth's rate of rotation by assuming that the entire rise is due to melting. If we take the sea level rise as being uniformly distributed over the globe and the latitude of the ice as 90° , again maximizing the effect, the sea level rise yields the change of rotation rate shown in Fig. 1, curve b. The observed rotation rate (Fig. 1, curve c) exhibits much larger changes. Munk and Revelle (4) have suggested that variable motion

in the earth's core may be the principal cause of the variations of rotation rate. Even the slight long-term trend in the observed rotation, more apparent in the 300-year record (5), is due largely to tidal friction (5, 6). The correlation coefficient between curves b and c in Fig. 1 is 0.0, or -0.3 if the observed change of rotation rate is corrected for tidal friction. We conclude that the melting of ice sheets is not the primary cause of observed variations in the earth's rotation rate during the past century.

An upper limit for global cooling due to polar ice discharge can be estimated by assuming that all 10 cm of the global sea level rise is due to polar ice discharge. The latent heat required to melt this ice is $10 \text{ g} \times 80 \text{ cal g}^{-1} = 800 \text{ cal}$ for each square centimeter of the global ocean. The mean ocean depth mixed at some time during the annual cycle is 125 m (7). Thus the global mean cooling would be $\sim 0.06^\circ\text{C}$, for the extreme case in which the discharge occurs rapidly and in which the thermal perturbation is confined to the annual-maximum mixed layer depth. However, any such cooling increases the flux of heat into the ocean [see equation 9 of (8)], which tends to negate the cooling effect of ice added at a time earlier than the thermal relaxation time of the ocean surface. This relaxation time is perhaps 5 to 20 years (3, 8), but the larger of these values would imply substantial exchange to depths beneath the mixed layer and thus a reduction of the global cooling estimated above. Use of global mean mixed layer depth maximizes the calculated global mean cooling: actually, ice melting oc-

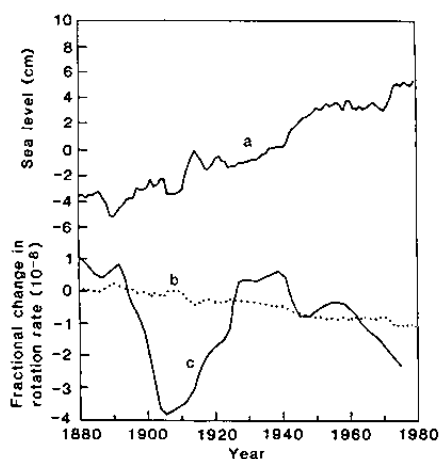


Fig. 1. Five-year mean global sea level trend (curve a) estimated from tide gauge data after correction for long-term shoreline movements. This sea level change, if entirely due to polar ice melting, would cause the change in the earth's rotation rate indicated by curve b for a terrestrial moment of inertia of $8 \times 10^{37} \text{ kg m}^2$. Curve c shows the observed trend of rotation rate (10).

curs at high latitudes where the annual-maximum mixed layer thickness is larger. We conclude that global cooling due to polar ice discharge has not exceeded a few hundredths of a degree centigrade in the past century, and thus this phenomenon does not affect interpretation of global mean temperature trends for this period.

Our conclusions that melting polar ice has small effects on global temperature and rotation rate apply to a rate of polar ice discharge of $10 \pm 5 \text{ cm}$ of sea level per 100 years. However, the effect on rotation will become substantial for a rate of melting several times larger. The location of the pole of rotation may also shift measurably, depending on the geographical source of the melting ice (6). The location of melting ice could be accurately measured by satellite monitoring of ice sheet topography (9).

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References and Notes

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The intent of our report (1) was to point out that several seemingly separate geophysical quantities are related to one another through physical processes that may be important in climate change, and to propose that the rise of sea level over the past 40 years is due in part to the net reduction of polar ice. We tried to make the case that some published interpretations of global sea level and temperature records over recent decades are consist-